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Analysis of some recharge solutions on varying the R407C composition

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ABSTRACT

In the vapour compression plants possible leaks can vary the composition of a zeotropic refrigerant mixture. The main aim of this paper is to verify experimentally if the plant performances are restored with a proper recharge, when leaks are imposed. As for the R407C mixture the percentage of the less volatile component (R134a) increases, while the percentage of the more volatile components (R32 and R125) decreases when leaks occur. The experimental tests have been realized determining refrigerant leaks from the liquid receiver placed at the condenser outlet and measuring the properties in steady state condition. The recharge is realized in different ways: with R407C, with R134a and R410A or with R32 R125 and R134a. The different solutions are then compared from the economical point of view, in terms of COP, refrigeration power and air temperature at the evaporator outlet, adopting an iteration method. This method determines the real composition of a zeotropic mixture working in a compression plant, when only the temperature and pressure values at the expansion valve inlet and outlet are known.

1. Introduction

The problem related to leaks of a zeotropic refrigerant mixture in the vapour compression plants is examined in this paper. Many authors have realized comparisons between the pure refrigerants and refrigerant mixtures performances. In [1] the authors have analyzed how the mixture attributes influence the heat exchanger design, performance and operation of vapour compression systems. It is also discussed how the temperature glide and composition shift can improve the system performance. The [2] identifies a reduction in terms of efficiency when mixtures are used instead of pure fluids. The cause of this problem is examined, and different alternative system configurations are evaluated. In [3] the performance of a heat pump has been experimentally investigated; pure R22, pure R134a and some binary mixtures of R22/R134a have been considered as working fluids. In [4] the impact on the performance of the charged composition of a ternary blend related to a domestic reversible heat pump is presented. In [5] the performance analysis of an air-to-water heat pump using pure refrigerants and zeotropic refrigerant mixtures is presented. Comparisons are made between the pure refrigerants and refrigerant mixtures in terms of COP and second law efficiency; it was found that the mixture ratio affects the COP and the second law efficiency considerably. The nominal composition of a zeotropic mixture can vary when it is working in a compression plant. This variation can be determined by two different phenomena: the thermodynamic and hydrodynamic behaviour of the circulating fluids (refrigerant and oil) and the plant design. In particular, the principal causes of the composition variation for a zeotropic mixture are: the velocity slip between liquid and vapour phases in heat exchangers, the different solubility of the mixture components in the lubricant used in the unit, the sealing quality of the various components of the plant [6]. When the composition varies the relation between the pressure and the temperature changes too, hence the use of this relation for the nominal composition might lead to wrong results. For this reason it is important to determine the exact refrigerant composition working in the plant to evaluate the plant performances correctly. In [7] a local simulation model of a water-to-water heat pump is proposed by adopting a modular approach. The computer simulation allows to evaluate the local temperature, the heat transfer coefficient along heat exchangers and the local composition of the refrigerant in each point of the circuit. The paper [8] reports on the development of a fault diagnosis and refrigerant leak detection system, based on artificial intelligence and real-time performance monitoring. Several authors studied the overall composition shift of zeotropic blends in heat pumps and their impact on their thermodynamic performances. In [9,10] the objective has been to investigate the effects of the expansion device on the performance of a heat pump at various charging conditions. In [11] the authors have experimentally investigated the performance of a heat pump with a capillary tube and EEV under various charging conditions. In [12] the results of experimental investigations about the effect of the refrigerant charge on the steady state system performance are presented, and parameters sensitive to the charge level for on-line leak detection in compression refrigeration systems

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Nomenclature

COP	coefficient of performance
h	specific enthalpy, J/kg
n	number of moles, mol
p	pressure, bar
Q	vapour quality, mol/mol
T	temperature, °C
u	specific internal energy, J/kg
V	volume, m^3
z	mole fraction, mol/mol
ρ	density, kg/m^3

Subscripts and superscripts

in	inlet
out	outlet
x	liquid phase
y	vapour phase
′	after leakage

are identified. The majority of the above described investigations were carried out on the heat pump performances when leaks happen, little has been reported on the effect of the possible solutions of the refrigerant recharges when leaks occur in a refrigeration plant. This paper, referring to the zeotropic mixture R407C (R32/R125/R134a 23/25/52% in mass), presents results of experimental investigations about the effect of the refrigerant recharge on the performance of a refrigeration plant linked to a cold store. The main aim is to verify experimentally if, imposing proper leaks, the initial conditions in terms of plant performances are restored with a proper recharge realized in different ways: with R407C, with R134a and R410A or with R32 R125 and R134a. The different solutions are then compared from the economical point of view, in terms of COP, refrigeration power and air temperature at the evaporator outlet. For this purpose an iteration method determining the real composition of a zeotropic mixture is realized. The routine receives as input data the values experimentally obtained of the mixture temperature and pressure in the cycle key-points, and determines the mixture composition and properties, and the fundamental parameters that allow the plant performances analysis. The experimental tests have been realized determining the refrigerant leaks from the liquid receiver placed at the condenser outlet.

2. Fundamental principles

In order to determine a method able to evaluate in a vapour compression plant the zeotropic mixture composition variation due to the inevitable leaks, it is necessary to describe the fundamental principles that allow to determine the thermodynamic equilibrium state after a leak. Assume that a tank (Fig. 1) with volume V is charged with n_z moles of a zeotropic mixture with nominal composition in liquid–vapour conditions at the equilibrium. When the equilibrium is settled, a number of n_x moles is in liquid phase and a number of n_y is in vapour phase ($n_z = n_x + n_y$), and then the vapour mole quality (Q) is equal to: $Q = n_y/n_z$; referring to the ith component of the mixture: $n_{z,i} = n_{x,i} + n_{y,i}$. The mole fraction of the ith component is $z_i = \frac{n_{z,i}}{n_z}$, the mole fraction of the liquid phase $x_i = \frac{n_{x,i}}{n_x}$ and the mole fraction of the vapour phase $y_i = \frac{n_{y,i}}{n_y}$. Hence, it is possible to obtain the following equations: $z_i = \frac{n_x x_i + n_y y_i}{n_z}$ and $z_i = x_i(1-Q) + y_i Q$.

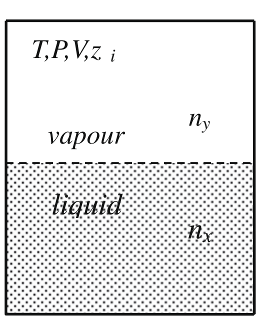

Fig. 1. Tank with n_z moles of a zeotropic mixture.

Considering the initial conditions before described and supposing that the tank presents a leak of Δn moles of vapour or liquid (Δn_y or Δn_x), the new composition of the zeotropic mixture is represented by the following equations:

$$\text{(liquid leakage)}\ z'_i = \frac{(n_x - \Delta n_x)x_i + n_y y_i}{n_z - \Delta n_x}$$

$$\text{(vapour leakage)}\ z'_i = \frac{n_x x_i + (n_y - \Delta n_y)y_i}{n_z - \Delta n_y}$$

Two types of leaks have been considered: isothermal and adiabatic. In the *isothermal* model the temperature is kept constant and the new equilibrium state of the zeotropic mixture after the leak is defined by:

$$\text{(liquid leakage)}\ T' = T \quad \rho' = (1-\alpha_x)\rho \quad z'_i = \frac{(1-Q-\alpha_x)x_i + y_i Q}{1-\alpha_x}$$

$$\text{(vapour leakage)}\ T' = T \quad \rho' = \rho(1-\alpha_y) \quad z'_i = \frac{(1-Q)x_i + (Q-\alpha_y)y_i}{1-\alpha_y}$$

The *adiabatic* model is characterized by no heat transfer through the container wall, hence the internal energy is the sum of the internal energy of the liquid and vapour phase minus the enthalpy of the refrigerant that is leaked out. The internal energy allows to define the new equilibrium state together with the density and the mole fraction:

$$\text{(liquid leakage)}\ u'_z = \frac{u_z - h_x\alpha_x}{1-\alpha_x} \quad \rho' = \rho(1-\alpha_x) \quad z'_i = \frac{(1-Q-\alpha_x)x_i + y_i Q}{1-\alpha_x}$$

$$\text{(vapour leakage)}\ u'_z = \frac{u_z - h_y\alpha_y}{1-\alpha_y} \quad \rho' = \rho(1-\alpha_y) \quad z'_i = \frac{(1-Q)x_i + (Q-\alpha_y)y_i}{1-\alpha_y}$$

where $\alpha_x = \frac{\Delta n_x}{n_z}$ and $\alpha_y = \frac{\Delta n_y}{n_z}$.

To determine a method able to evaluate the real composition in a vapour compression plant when R407C is used as working fluid, it has been necessary at first to obtain an analytical equation that linked the mole fractions of the R134a and R32, considered components of the mixture R407C subjected to leaks. For this aim many theoretical simulations of leaks have been determined considering liquid and vapour leaks both adiabatic and isotherm; the results have been represented in Fig. 2. As reported in Fig. 2, the different points are present on the same curve, and it is possible to obtain an equation adoptable for all types of possible leaks:

$$z_{R134a} = -0.948 \cdot z_{R32}^3 + 1.18 \cdot z_{R32}^2 - 1.77 \cdot z_{R32} + 0.994 \qquad (1)$$

3. Composition determination method

The method is based on the equality of the refrigerant fluid enthalpy values at the expansion valve inlet and outlet. As the

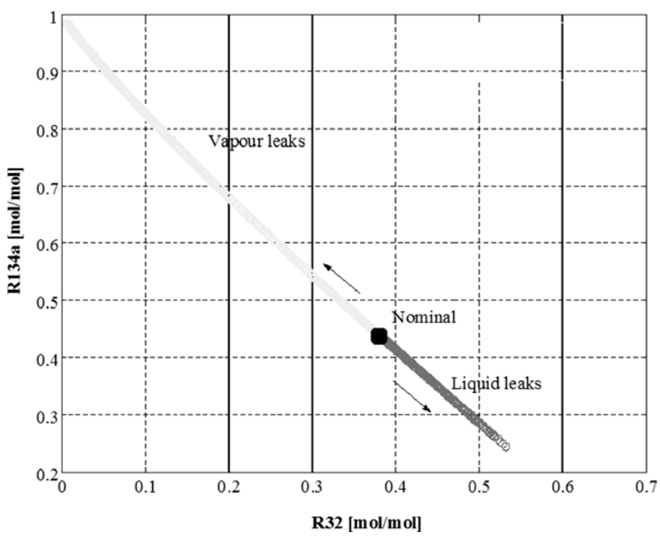

Fig. 2. Mole fractions of the R134a and R32.

mixture enthalpy is function of the temperature, pressure and its composition, for an expansion valve it is possible to write for the R407C:

$$h_{in}(T_{in}, p_{in}, z_{R125}, z_{R32}, z_{R134a}) = h_{out}(T_{out}, p_{out}, z_{R125}, z_{R32}, z_{R134a}) \quad (2)$$

where z represents the mole fraction of a generic component of R407C. In particular, the enthalpy values at the valve inlet and outlet will be equal only for the mixture nominal composition. On the contrary if the R407C passes through the valve with a composition different from the nominal one and the enthalpies are evaluated adopting the nominal composition, the enthalpy value at the valve outlet will be higher or lower than the value at the valve inlet. If the mixture is enriched with more volatile components (R32 and R125), the pressure at the valve outlet will be greater than the pressure of the mixture at the nominal composition and the enthalpy will be minor. On the contrary if the mixture is enriched with less volatile component (R134a), the pressure at the valve outlet will be lower than the pressure of the mixture at the nominal composition and the enthalpy will be higher (Fig. 3). Hence, it is possible to have the following system of three equations and three unknowns:

$$\begin{aligned} &h_{in}(T_{in}, p_{in}, z_{R125}, z_{R32}, z_{R134a}) = h_{out}(T_{out}, p_{out}, z_{R125}, z_{R32}, z_{R134a}) \\ &z_{R134a} = -0.948 \cdot z_{R32}^3 + 1.18 \cdot z_{R32}^2 - 1.77 \cdot z_{R32} + 0.994 \\ &z_{R125} = 1 - z_{R32} - z_{R134a} \end{aligned} \quad (3)$$

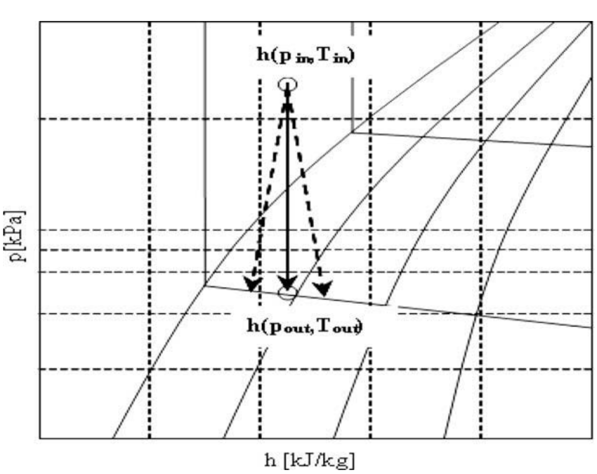

Fig. 3. *p–h* Chart.

The system unknowns are the three mole fractions, while the temperatures and pressures can be obtained by means of experimental tests. Hence, the subsystem Γ can be indicated with:

$$\Gamma \begin{cases} z_{R134a} = -0.948 \cdot z_{R32}^3 + 1.18 \cdot z_{R32}^2 - 1.77 \cdot z_{R32} + 0.994 \\ z_{R125} = 1 - z_{R32} - z_{R134a} \end{cases} \quad (4)$$

that clearly presents infinite solutions. If the mole fraction of the R32 is fixed, the mole fractions of R125 and R134a are determined solving Γ. For this reason the mole fractions of R125 and R134a are functions of the R32 mol fraction by means of Γ: $\{z_{R125}, z_{R134a}\} = \Gamma(z_{R32})$ and the vector $\mathbf{z}$ is known if z_{R32} is known:

$$\mathbf{z} = \{z_{R32}, \Gamma(z_{R32})\} \Rightarrow \mathbf{z} = \mathbf{z}(z_{R32}) \quad (5)$$

Hence, it is possible to consider a one equation with only an unknown instead of a system of three equations in three unknowns:

$$h_{in}(T_{in}, p_{in}, \mathbf{z}(z_{R32})) = h_{out}(T_{out}, p_{out}, \mathbf{z}(z_{R32})) \quad (6)$$

It is possible to transform the solution of Eq. (6) into a problem for the determination of the zeros of the function $\varepsilon = 1 - h_{out}/h_{in}$. It is evident that the research of the zero of function ε is equivalent to determine the composition that determines the equality $h_{in} = h_{out}$. To evaluate the mixture enthalpy it is possible to adopt the subroutines of the software Refprop 7.0 [13] and, in particular, the subroutine TPFLSH, that receives as input the temperature the pressure and the mixture composition and gives as output the other thermodynamic properties:

$$\{\rho, \rho_L, \rho_V, \mathbf{x}, \mathbf{y}, Q, u, h, s, cv, cp, w\} = TPFLSH(T, p, \mathbf{z}) \quad (7)$$

It has been adopted the bisection iteration method that determines a range containing the function zero, equal to half of the former range and assumes as approximation of the zero the abscissa of the range middle point. The bisection method needs two initial values of the variable that include the solution researched; denoting these two values with z_a and z_b, the first operation related to these values is the evaluation of the function ε. The iteration method continues until ε results lower than a prefixed value. The iteration algorithm built in Visual Basic environment utilizes, as above said, some subroutines of the Refprop library [13]. This method allows to obtain the thermodynamic equilibrium state of any zeotropic mixtures characterized by leaks. Moreover, by means of the iteration algorithm the thermodynamic properties in the key-points of the refrigeration cycle can be determined. Hence, it is possible to obtain the COP, the superheating, the subcooling and the compression ratio. The above described program will be adopted to determine the real composition of the mixture and the plant performances in consequence of the working fluid leaks, measuring experimentally the pressure and temperature values at the expansion valve inlet and outlet.

4. Experimental plant

The experimental vapour compression refrigeration plant, subjected to a commercially available cold store and reported in Fig. 4, is made up of a manifold with two expansion valves (thermostatic and manual) to feed an air cooling evaporator inside the cold store, a semi-hermetic reciprocating compressor, an air condenser followed by a liquid receiver. The fluid refrigerant experimentally tested is the R407C. To fix the air temperature on the condenser and to simulate variable external conditions, the air flows under the influence of a blower in a thermally insulated channel where some electrical resistances are located. In order to obtain exactly the same temperature settled for the air, a regulator is used to control the electrical resistances supply. The cooling load has been simulated by means of an electric heater located in the cold store

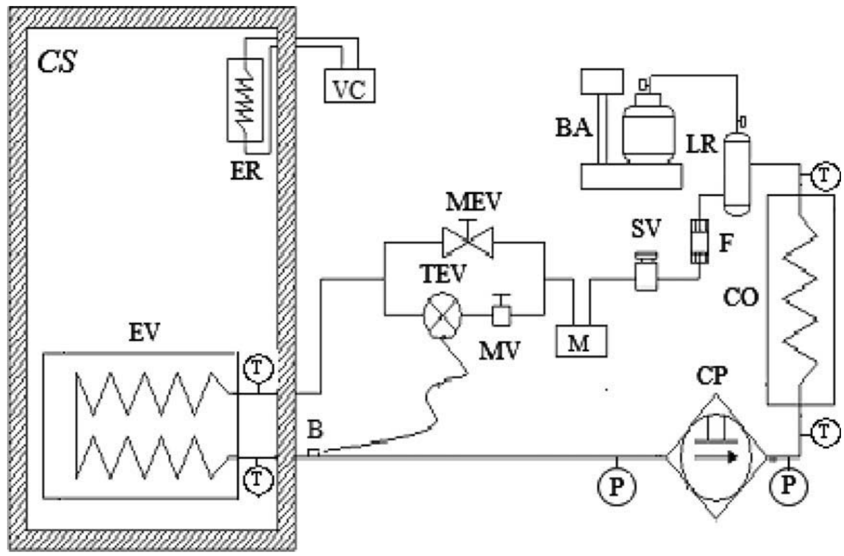

Fig. 4. Experimental plant. CS: cold store; EV: evaporator; CP: compressor; CO: condenser; LR: liquid receiver; F: filter; SV: solenoid valve; MV: manual valve; MEV: manual expansion valve; TEV: thermostatic expansion valve; B: bulb; ER: electric resistances; VC: voltage converter; BA: balance; M: refrigerant mass flow rate sensor; T: temperature sensor; and P: pressure sensor.

and linked to an electric voltage regulator and the electric power is measured by means of a wattmeter. The transducers specifications adopted are reported in Table 1 (RTD 1000 4 wires thermoresistances, piezoelectric absolute pressure gauge, wattmeter, Coriolis effect flowmeter).

5. Experimental tests

Different leaks of the R407C refrigerant fluid have been experimentally determined and the measurement of the mixture properties in the plant key-points has been realized. In particular, it has been important to measure the refrigerant temperatures at the condenser inlet and the condenser outlet (valve inlet), the refrigerant temperatures at the evaporator inlet (valve outlet) and the evaporator outlet, the low and high pressures and the refrigerant mass flow rate. The experimental values of the above mentioned properties are adopted in the previously described method which allows to evaluate the mixture composition and the fundamental plant parameters. In order to realize a variation of the zeotropic mixture composition, first of all it is necessary to determine the leak in a component of the plant where the liquid phase and the vapour phase are in equilibrium. Moreover, the leak must be realized in a point of the component in contact with a single phase, liquid or vapour. It is possible to have these conditions in the liquid receiver placed at the condenser outlet. Generally in the liquid receiver the liquid is located at the bottom of the receiver, while in the upper part the vapour is in steady state condition in equilibrium with the liquid phase. It is necessary to observe that the liquid phase presents for the R407C a composition near the global one, hence its leak might not cause the mixture composition variation. On the contrary the vapour phase has a composition different from the global one and its leak might cause the global composition variation. Hence, it has been considered the leak from the upper part of the liquid receiver where there is vapour; the high pressure of the refrigerant fluid in the receiver allows to determine leaks up to 60% of the initial charge without sucking the refrigerant fluid, but this is due only to the pressure difference between the receiver and the bottle utilized to collect the leaks. The upper part of the liquid receiver has been linked to a small bottle (Fig. 4) where the vapour that comes from the liquid receiver is collected; the bottle has been placed on a precision balance in order to measure the weight of the vapour mass lost. At first, related to the steady state condition, a first acquisition has been realized without determining leaks to verify the inevitable shifting between the real composition and the nominal composition due also to the plant charge operation; in fact charging the only liquid phase it is possible to limit the composition variation but not to avoid it completely. To realize the first leak it is necessary to open the joint between the liquid receiver and the bottle, until the value of about 160 g (after about 10 s) is on the analogical display of the precision balance, where the bottle is located. Once reached the steady state condition the data acquisition begins; in this way the other leaks have been realized. At the end of the experimental tests, the mixture remains in the refrigeration plant with a composition different from the initial one. In each test the plant has been charged with 1.75 kg of R407C. In particular, the following experimental tests have been realized:

- full plant (reference test), leak of the initial charge 30%, recharge of 30% of R407C previously lost, leak of the initial charge 30%, recharge of 30% of R407C previously lost;
- full plant (reference test), leaks of 10%, 20%, 30%, 40% and 50% of the initial charge, recharge of R407C previously lost;
- full plant (reference test), leak of the initial charge 50%, recharge of R134a and R410A (azeotropic mixture, 50% of R32 and 50% of R125 in mass);
- full plant (reference test), leak of the initial charge 50%, recharge with R32 R125 and R134a; in these tests the recharge has been realized with R32 R125 and R134a obtaining the exact composition by means of the software.

Table 1
Transducers specifications.

Transducer	Range	Accuracy
Coriolis effect mass flow rate meter	0 ÷ 2 kg/min	±0.2%
RTD 1000 4 wires	−100 ÷ 500 C	±0.15 C
Piezoelectric absolute pressure gauge	1 ÷ 10 bar; 1 ÷ 30 bar	±0.2; ±0.5 F.S
Wattmeter	0 ÷ 3 kW	±0.2%
Electric energy meter	0 ÷ 1000 MWh	±1.0%

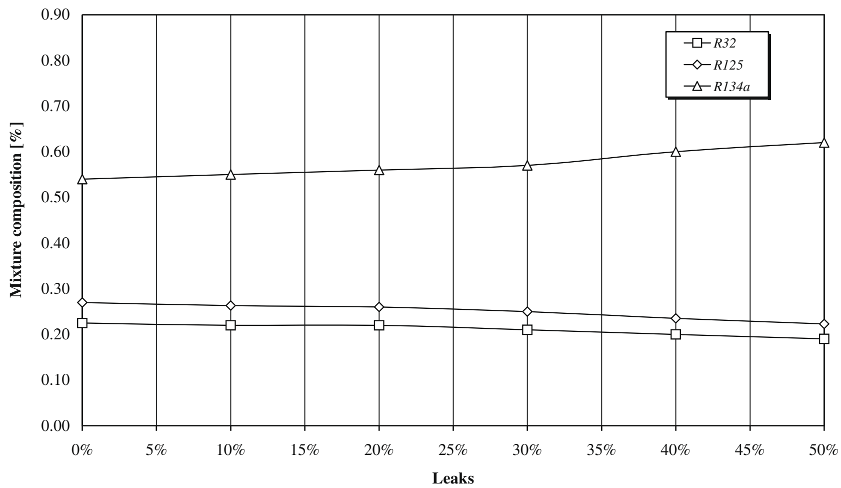

Fig. 5. R407C components composition.

6. Results and discussion

In Fig. 5 the R407C components composition has been reported; in particular, it has been evaluated by means of the method above described, and represented in function of the working refrigerant fluid leaks (10%, 20%, 30%, 40% and 50% of the initial charge). The composition of the R407C components, the plant COP and the cycle properties have been determined by varying the refrigerant leaks by means of the software, adopting as input data the medium values of the high and low pressure, and the temperatures at the inlet and outlet of the evaporator and condenser obtained experimentally. It is possible to observe that owing to the leaks of the vapour, the percentage of the less volatile component (R134a) increases, while the percentage of the more volatile components (R32 and R125) decreases. The composition variations are small up to values of the leaks lower than about 20% of the initial mass, while they increase when this percentage value is higher. Comparing the theoretical trends of the R407C composition with the ones obtained with the above explained method, it has been noted that the variation of the components percentage of the R407C working in the experimental plant results congruent with that obtainable theoretically by varying the leaks, and nearer the adiabatic situation in comparison with the isothermal one. This can be explained observing that the vapour in the liquid receiver is at a very high pressure and then the vapour goes out with high velocity when the tap is opened. Hence, it is possible that during the leak the mass present in the receiver has not time to interact with the outdoor environment through the walls, and therefore the leak takes place adiabatically. It has been possible to realize the experimental test with a leak equal to 60% only in winter conditions, and not in summer conditions, owing to the high outdoor temperatures that do not allow the convergence of the software. Moreover, Fig. 5 shows out as the curves that represent the composition variation of the fluids R32 and R125 present a similar slope when the leaks increase; hence, it is possible to realize a recharge with R410A (50% of R32 and 50% of R125 in mass) and R134a, tolerating a negligible error. Once obtained the leaks the plant has been fully recharged in different ways: with R407C, with R134a and R410A, with R32 R125 and R134a. When the recharge is realized with the refrigerant fluid R407C, it has been observed a small increase of the R134a percentage, and this can determine an air temperature increase at the evaporator outlet because the R134a is the least volatile component and the fluid presents a higher evaporation temperature; hence, an increase of this component allows an evaporation temperature increase of the mixture. Referring to the second type of recharge, the R134a of the lost amount is introduced, while the R32 and the R125 are introduced with equal amount by means of the recharge of R410A (50% of R32 and 50% of R125 in mass) allowing a deviation in comparison with the initial fractions equal to about 3%. Finally the last recharge results the most exact, in fact the plant is charged with the amount of R32 R125 and R134a lost. However it is necessary to observe that it is difficult to decrease during the recharge the uncertainties due to the balance uncertainty and the operator. Comparing the composition after the recharge, it can be observed, for example that, recharging 50% of the working fluid, the compositions of R32, R125 and R134a result very near the initial fractions before imposing any leak type. Obviously it is observed a deviation higher when the plant has been recharged with only the R407C because the leak of R407C occurs in the vapour phase, on the contrary the recharge of R407C happens in the liquid phase. In Fig. 6 the COP values are compared when a leak of 30% of initial charge is repeated two times, and when the recharge is realized with only R407C. Firstly it is possible to observe that the COP decreases, after a leak of 30%, of about 11%. Moreover, it can be noted that recharging only with the refrigerant R407C, the COP decreases when the recharges number increases; in particular, after two recharges the COP decreases of about 5% while the refrigeration power decreases of about 8% (Fig. 6). Moreover, the refrigerant leak determines an air temperature increase in the cold store as reported in Fig. 7. With a leak of 50% in Fig. 8, referring to the experimental tests realized both without leaks and with the above mentioned three types of recharge realized just once, it is possible to obtain with the recharge of R32 R125 and R134a the most approximate COP to the situation without leaks. In fact the recharge realized with R407C determines a decrease in terms of COP of more than 6%, the second type of recharge of more than 4% and, finally, the last type of recharge a decrease under 2%. Moreover, for a further control, the COP has been determined as ratio between the refrigeration power determined from the air side and the compressor electric power (COP_{out}). Both for the COP determined from the refrigerant side (COP_{int}) and for the COP_{out} the same decrease has been verified after one recharge. An uncertainty of ±0.45% has been determined for the COP_{int} and of ±3.0% for the COP_{out}. Besides, referring to 50% leaks, it can be noted in Fig. 8 as the minor decrease of the refrigeration power is obtained with more accurate recharge. This situation is explainable considering that the composition of R134a, when the recharge is realized with the refrigerant R407C in liquid phase, is lightly higher in comparison with the nominal one, determining a refrig-

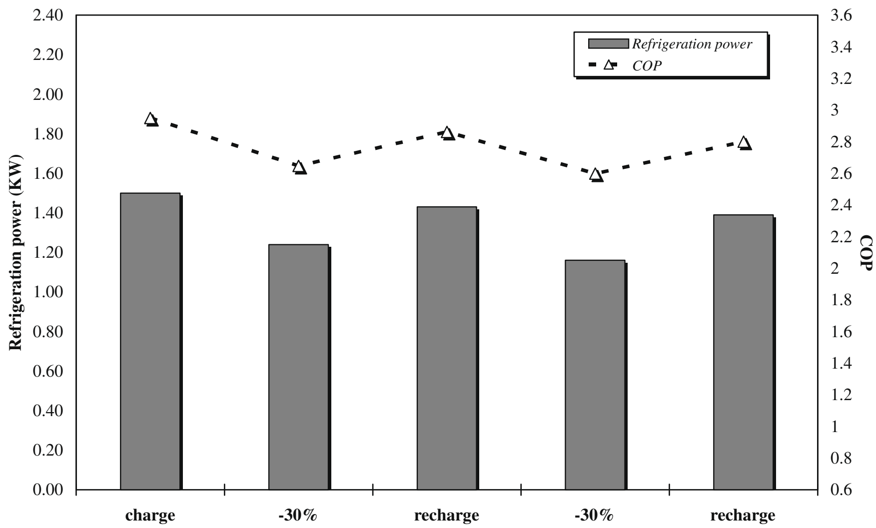

Fig. 6. COP and refrigeration power related to leaks of 30%.

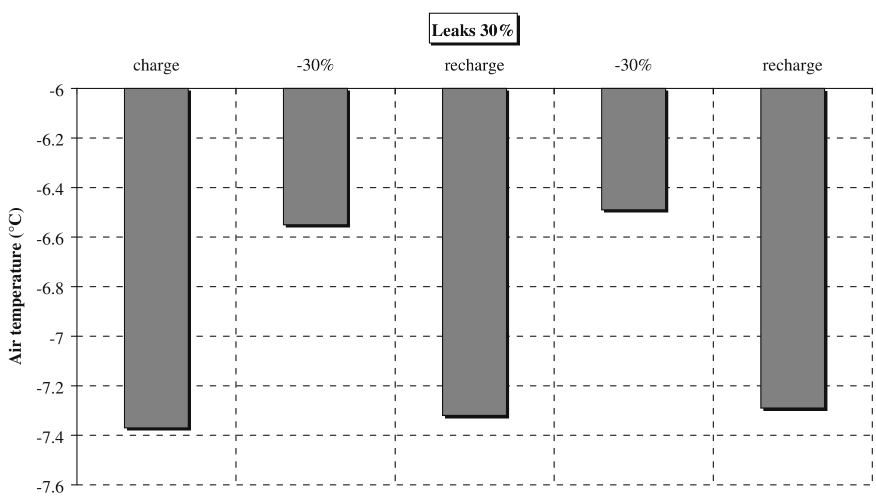

Fig. 7. Air temperature in the cold store.

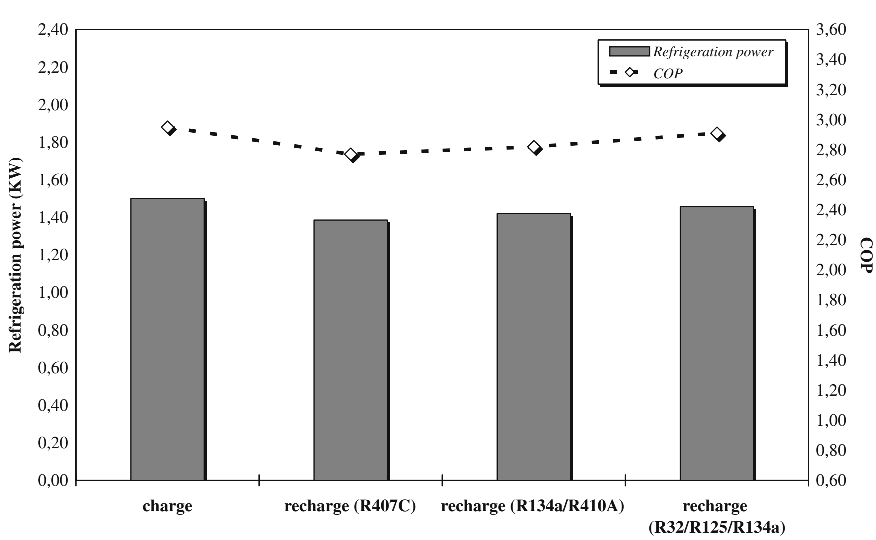

Fig. 8. COP and refrigeration power related to three types of recharge.

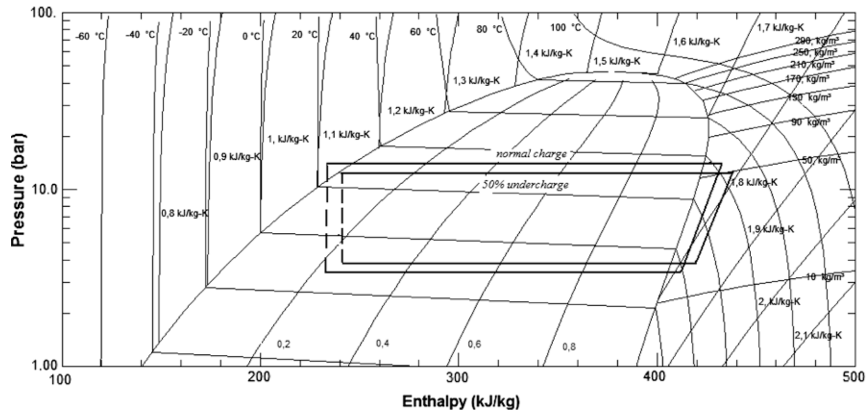

Fig. 9. Pressure–enthalpy diagram for various charge levels.

erant fluid temperature increase and then an increase of the air temperature at the outlet of the evaporator. Moreover, it has been experimentally observed that the air temperature difference at the evaporator is lower with the recharge with only R407C. Finally it has been experimentally noted that from the energy saving point of view the best way to recharge a vapour compression plant where the working fluid is a zeotropic mixture, is to recharge the amount exactly lost. To obtain this it is necessary, as above said, to have a program that allows the determination of the exact composition of R407C and to have at disposal the refrigerant fluids that compose the mixture. The iteration method allows to determine the real composition of a zeotropic mixture when only the pressure and temperature values at the expansion valve inlet and outlet are known. In particular, the problem of the leaks has been associated with the changing solubility of the components of the mixture not only when the pressure and temperature change, but when other properties vary too. In this regard, the *p*–*h* phase diagram (Fig. 9) is represented referring to the normal charge of R407C and to 50% undercharge; the pressure, the temperature, the specific enthalpy, the specific volume, the specific entropy, the quality are reported on varying the mixture composition. Moreover, to know the exact composition of R407C components on varying the leaks, in Fig. 10 the mixture composition has been reported in terms of the valve outlet refrigerant temperature and the compression ratio. Unfortunately the difficulty to find on the market at low cost the R32 and R125, involves the research of alternative solutions. The solutions proposed in this paper are: the recharge with R407C and the recharge with R134a and R410A; from the energy saving point of view, the second option is surely more advantageous. Finally it is preferable to realize a more exact recharge with R32 R125 and R134a when the composition is very different from the nominal one. On the contrary if the composition due to a leak is near the nominal one, it is possible to realize the recharge simply with the R407C. Besides an economical analysis can be realized considering that the COP decreases depending on the type of above mentioned refrigerant recharge. To realize an economical analysis the following hypotheses have been considered: R407C as refrigerant fluid; refrigeration power of 50 kW; a leak of 50% after a plant working of 10 years; medium cost of kWh_{el}: 0.15 €/kWh_{el}; annual COP decrease constant. From the economical comparison among different possibilities of recharge examined in this paper, it can be deduced that the higher advantages have been obtained with the recharge of the single components R32, R125 and R134a. In particular, it is possible to observe that an economical saving of about 20% with the recharge of R32, R125 and R134a is obtained in comparison with the recharge with only R407C, and of about 10% adopting the recharge with R32, R125 and R134a respect to the mixture of R410A and R134a. This situation results convenient only for the high size plants, because there is the possibility to buy considerable amount of the refrigerant fluids R125 and R32, obtaining in this way a decrease of the costs. In fact from marketing researches the purchase of these fluids in small amount allows

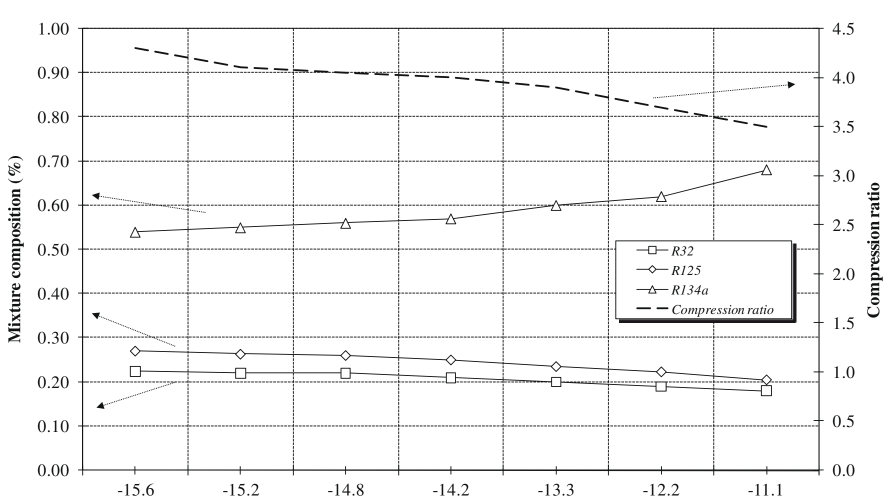

Fig. 10. Refrigerant temperature and compression ratio on varying the refrigerant leaks.

high costs; on the contrary, if it is necessary to buy a big amount of refrigerant fluid, the cost might be comparable with that of others refrigerant fluids easily available on the market.

7. Conclusions

In this paper the refrigeration plant performances working with the zeotropic mixture R407C have been determined by means of a software when, after proper leaks, the plant has been charged before with R407C, then with R410A and R134a, and finally with R32 R125 and R134a. The iteration method allows to evaluate the real composition of the R407C working in a vapour compression plant, when only the pressure and temperature values at the expansion valve inlet and outlet are experimentally known. In particular, the method described allows to verify experimentally, once known the mixture components mass discharged in the environment, if the plant performances are the same when the single components mass is again integrated in the plant. First of all it has been observed that in consequence of the vapour leaks, the percentage of the less volatile component (R134a) increases, while the percentage of the more volatile components (R32 and R125) decrease. The composition variations are small up to values of the leaks lower than about 20% of the initial mass, while they increase when this percentage value is higher. Comparing the composition theoretical trends with the ones obtained in this paper, it has been possible to observe that the two situations are nearer the adiabatic situation respect to the isothermal one. This is explainable observing that the vapour in the liquid receiver is at a very high pressure and, when the tap is opened, the vapour goes out with high velocity; hence, it is possible that during the leak the mass in the receiver has no time to interact with the outdoor environment through the walls and therefore the leak occurs adiabatically. In particular, it has been observed that the plant performances in terms of COP and refrigeration power decrease when continuous recharges of R407C have been realized. Moreover, from the experimental analysis it has been established that the recharge with R32, R125 and R134a is the best in terms of COP, refrigeration power and air temperature at the evaporator outlet. On the contrary from the economical point of view, it has been observed that it is preferable for the low-medium size plants to realize the recharge with R407C or R134a and R410A, because these refrigerant fluids are cheaper and easily available in comparison with R32 and R125. As for the big size plants the recharges with R32 R125 and R134a might be more convenient because it is possible to buy the refrigerant fluids R125 and R32 in large quantities with a consequent cost decrease.

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